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Method for Generating a Stereoscopic Image of an Object and an Arrangement for Stereoscopic Viewing

Related Applications

This is a continuation-in-part of United States patent application serial no. 09/505,724, filed February 17, 2000, which, in turn, is a continuation application of United States patent application serial no. 08/881,278, filed June 24, 1997 (now abandoned), which, in turn, is a continuation-in-part application of application serial no. 08/610,455, filed March 4, 1996, (now United States Patent 5,835,246).

Background of the Invention

The known stereoscopic arrangements are based on two separate microscopic beam paths for respective eyes of the viewer. The conventional arrangements are the Greenough type and the Galilei type. Both types have the disadvantage which is the limitation of microscopic resolution so that apertures greater than 0.1 are possible only with substantial complexity. This comes about because large working distances are desired in stereo arrangements and since, for conventional arrangements, only limited aperture space is present because of the following: the required angle for the stereo viewing, the two separate beam paths and the frame parts of the two beam paths with manipulable dimensioning.

It is further known to insert half diaphragms in the form of polarization filters in the condenser of a single-objective microscope in order to obtain a stereoscopic effect. The polarization directions of the polarization filters are mutually perpendicular and correspondingly orientated polarization filters must be provided in the two tubes. In this connection, reference

can be made to the "Journal of Microscopy", volume 153, February 1989, pages 181 to 186.

Published German patent application 4,311,603 discloses a stereomicroscope having a high magnification wherein an object translator is provided in the beam path on the object side of a single-objective light microscope in the object plane. A beam switchover device is mounted in the beam path on the image side. Disadvantageous is here the object translator because the movement of the translator can lead to vibrations of the entire microscope, especially for objects having a large mass.

United States Patents 4,561,731 and 4,806,776 disclose that a pseudo stereoscopic effect can be generated with the aid of a so-called differential polarization illumination. For the illumination, two separate light sources are provided and polarizers are mounted downstream thereof for generating different polarization directions.

United States Patent 4,561,731 shows in FIG. 10 thereof and in the description corresponding thereto that a proper stereoscopic image can be generated in that polarizers are mounted in the light path of the oculars and a double refracting plate is mounted between objective and object. The single illuminating beam path is alternately polarized differently.

A similar arrangement is described in PCT patent publication WO 94/02872. Here too, two light sources and two beam paths are utilized.

This also applies to a surgical microscope disclosed in published German patent application DD-A5 290,278. Two illuminating systems lying diametrically opposite to each other are inclined to the optical axis and the image viewed in the right ocular is assigned to the first illuminating system and the

image viewed with the left ocular is assigned to the second illuminating system.

A method for generating stereoscopic images of an object is described in United States Patent 5,835,264, incorporated herein by reference. This method includes the steps of illuminating an object with an illuminating beam; masking the illuminating beam to generate a first component beam to illuminate the object at a first angle and provide a first image of the object to a first viewing eye; again masking the illuminating beam to generate a second component beam to illuminate the object at a second angle and to provide a second image of the object to a second viewing eye; and, alternately repeating the last two steps at a frequency above the flicker frequency of the human eye.

The arrangement for carrying out the above method includes a beam generating device for alternately generating first and second illuminating beam components which illuminate the object via illuminating optics at respectively different angles to produce respective images of the object. A directing device alternately directs the images to the left and right eyes of a viewer at a frequency above the flicker frequency of the human eye.

Stereoscopic viewing has as a condition precedent that the viewing is through both eyes. It is based on the fact that, because of the spacing of the eyes, the viewing direction toward an object is different for each eye and therefore the two retinal images are not identical. It is only in the brain that the two images are processed to a single total impression which leads to a spatial display.

In conventional one-objective microscopes, one views also only one plane when using a binocular tube, namely, the focal

plane, that is, a narrow range of depth which corresponds to the depth of field. The objects, which are visible simultaneously within this region, appear all to be projected into the same plane because both eyes see the same image.

In order to arrive at a spatial image in microscopy, each eye must be offered a different microscopic image. The above can be two microscopic images which either are viewed for each eye at a different angle or are illuminated for each eye at a different angle. This stereo angle lies essentially in the region from approximately ± 7° to ± 15°.

An example for the utilization of the stereo observation at two different illuminating angles is a modification of the half-diaphragm method of Ernst Abbe as set forth in the text of H. Beyer entitled "Handbuch der Mikroskopie", second edition, VEB Verlag der Technik, Berlin, 1977, page 345, which is incorporated herein by reference.

Summary of the Invention

In view of the above, it is an object of the invention to supplement the embodiments described in the above-identified application with further advantageous embodiments and to optimally configure the entire microscopic arrangement with respect to resolution and depth of field as well as with respect to stereo impression.

The stereoscopic image of a self-luminous object such as a microscopic fluorescent object is especially advantageously generated in that the exit pupil of the objective is sectioned and is alternately supplied in a clocked manner to the left and right eyes at a frequency above the flicker frequency. It is advantageous to section the exit pupil into two lunes having respective centroids which are so adjustable that viewing of the

object at a variable stereo angle takes place while, simultaneously, the viewing aperture remains utilized to a maximum. In this way, a high microscopic resolution is achieved. In this method, transilluminated objects and incident-light illuminated objects can be viewed. Pupil sectioning takes place in one embodiment via a DMD mirror close to the exit pupil (DMD = Digital Micromirror Devices). Digital micromirror devices comprise a plurality of micromirrors having angle positions which can be electrostatically adjusted.

In a second embodiment, the pupil sectioning takes place in or close to the exit pupil via a light modulator such as a liquid crystal matrix. The image viewing takes place utilizing clocked image-recording and image-reproducing equipment, such as a video camera and monitor, or via clocked light modulators in the ocular beam path. The ocular beam paths can, however, also be clocked via a polarizing beam splitter having a switchable LCD cell.

In a third embodiment, the pupil sectioning takes place near the exit pupil via a high-resolution video camera. The image viewing takes place after a Fourier transformation of the two pupil images and clockwise reproduction for each eye via a monitor shutter or shutter spectacles.

It is further advantageous to mount diaphragms in or near the entry pupil of the microscope objective as well as in or near its exit pupil. The diaphragms are preferably adjustable and/or exchangeable.

It is still another object of the invention to provide a method and an arrangement for stereoscopic viewing of microscopic images with high resolution in normal transmitted-light microscopes and in reflected-light microscopes having variable depth of field and resolution.

The microscope arrangement of the invention is for generating a stereoscopic image of an object for viewing at a frequency greater than a flicker frequency. The microscope arrangement includes: a single microscope objective for imaging the object and defining an imaging beam path as well as an entry pupil and an exit pupil; an illuminating source for providing an illuminating beam; means at or near the entry pupil for receiving the illuminating beam and alternately blocking a section thereof to form two illuminating component beams at a clock frequency greater than the flicker frequency of the human eye; illuminating optics for transmitting the illuminating component beams to the object for illuminating the object at various angles; and, the illuminating optics including a diaphragm mounted in or near the receiving and blocking means.

The method of the invention for stereoscopic viewing microscopic images with high resolution is characterized by the following:

(a) in or near the aperture diaphragm plane of the illuminating beam path (entry pupil of the objective), a light modulator is provided which shifts the centroid of the illuminating beam into two positions at a clock frequency so that the object is illuminated at an angle required for the stereoscopic viewing with the maximum possible aperture;

(b) means are provided for alternately displaying the two images of the stereoscopic image pair on an image display apparatus and the clocking or pulsing of the image display apparatus takes place in synchronism with the clocking of the light modulator;

(c) the sequence or repetition frequency makes possible a flicker-free image impression; and,

(d) the variation of the depth of field and resolution takes place with a variable diaphragm approximately in the plane of the entry pupil or in the image thereof.

Brief Description of the Drawings

The invention will now be described with reference to the drawings wherein:

FIG. 1 is a schematic plan view of an arrangement for sectioning pupils utilizing a DMD mirror;

FIG. 2 is a side elevation view of the arrangement of FIG. 1;

FIG. 3 is a schematic representation of another embodiment of the arrangement according to the invention wherein pupil sectioning is performed utilizing a LCD modulator;

FIG. 4 is a schematic of another embodiment of the arrangement according to the invention wherein pupil sectioning is performed utilizing a LCD modulator and beam splitting via a switchable polarizing beam splitter;

FIG. 5a is a transilluminating light arrangement wherein a monitor and shutter spectacles are used for viewing and wherein the beam is shown for the illumination of the object O in a first cycle;

FIG. 5b shows the beam for the illumination of the object O in the second cycle in the context of the transmitted-light microscope of FIG. 5a;

FIG. 6a is an incident light arrangement wherein illumination is via a beam splitter and wherein the beam path is shown for a one-objective reflected-light microscope up to the video camera;

FIG. 6b shows the beam path for a one-objective reflected-light microscope having direct ocular viewing;

FIG. 7a shows the light relationships in the plane of the aperture diaphragm wherein a variable circular diaphragm is closed by a small amount;

FIG. 7 b shows the light relationships in the plane of the aperture diaphragm wherein a variable central diaphragm is mounted as an opaque circular diaphragm;

FIG. 7c shows the light relationships in the plane of the aperture diaphragm wherein a variable central diaphragm is mounted as an opaque rectangular diaphragm; and,

FIG. 8 is a schematic representation of the arrangement of the invention corresponding to FIG. 3 except that pupil sectioning is performed utilizing a DMD mirror.

Description of the Preferred Embodiments of the Invention

In FIGS. 1 and 2, the light of a self-luminous object O is received by objective OB. A tube lens T1 generates a first intermediate image on the far side of mirror S. A field lens FL generates an image of the exit pupil of the objective OB on a DMD mirror 2. The DMD mirror 2 sections the imaging beam into two component beams in a clocked manner for left and right oculars (OK1, OK2) so that the centroid of each component beam makes stereo viewing possible and the aperture is maximally utilized. The tube lenses (T21, T22) generate the intermediate image for the particular ocular. Deflection prisms (UP1, UP2) and prisms (P1, P2) guide the intermediate image of the ocular viewing. The spacing between the eyes of the viewer is adjustable by shifting the prisms (P1, P2) as indicated by double arrows 4 and 6.

In FIG. 3, an illuminator L illuminates the object O via a collector K and a condenser KO. The object O modulates the light or is excited to self-illumination (for example, fluorescence).

Condenser KO and objective OB image the entry pupil EP into the exit pupil AP. The field lens FL generates, via mirrors (S1, S2, S3), an image of the exit pupil AP in the plane of the light modulator LM which, for example, can be configured as a LCD modulator. The mirrors S2 and S3 can be advantageously coupled and displaced as a unit as indicated by double arrow 8 in FIG. 3 in order to precisely image the exit pupils of different objectives OB in the plane of the light modulator LM.

The tube lenses (TB1, TB2) ensure the imaging of the intermediate images of the object O in a video camera VK and, via beam splitter ST, in the binocular tube for the ocular viewing as indicated by arrow 10.

The LCD modulator LM sections the imaging beam into two component beams in a clocked manner so that the centroid of each component beam makes stereo viewing possible and the aperture is maximally utilized.

Sectioning of the exit pupil is possible which goes beyond simple sectional images, for example, by providing mutually overlapping lunes. A video camera VK assumes the particular image in a clocked manner. A drive controls the light modulator LM and the video camera VK so that in each case, one of the two images of a stereoscopic image pair is recorded. The display of the three-dimensional image takes place preferably via an electronic image screen. The viewer wears polarizing spectacles PB and views a monitor M via a monitor shutter MS which defines a switchable polarizing filter. The monitor shutter MS is mounted forward of the monitor M and is driven by drive A via line 12. The monitor shutter MS switches the polarization direction by 90° at a clock frequency pregiven by drive A. The monitor shutter MS and its position relative to the

monitor are described, for example, in a publication entitled "User Manual", publication no. 063-2071-00, published by NuVision Technologies, Beaverton, Oregon.

FIG. 8 is a schematic corresponding to the arrangement shown in FIG. 3 except that a DMD mirror is utilized for pupil sectioning in lieu of the LCD modulator.

The polarizing filter is triggered by the drive A with the change of the stereoscopic sectional images. Direct stereoscopic viewing via oculars (OK1, OK2) is also possible with a combination of a polarizing beam splitter PST and a LCD modulator as shown in FIG. 4. The mirrors S2 and S3 are coupled and displaceable in the direction of double arrow 8 as in FIG. 3.

If ferroelectric liquid crystal elements are used as a LCD modulator LM between two polarizing filters (P1, P2), then the second polarizing filter P2, as seen in light beam direction, can operate as a polarizing filter for a LCD cell which is connected to the drive A. This LCD cell rotates the polarizing direction of the incident light beam by 90° but does not change the polarizing direction and this is done in accordance with the applied electrical voltage.

The following polarizing beam splitter PST has a polarizing splitter layer, that is, the layer reflects light of a specific polarizing direction and light of the polarizing direction oscillating perpendicularly thereto passes through the splitter layer. The drive of the LCD modulator LM is so coupled to the drive of the LCD cell 12, that each eye, in combination with the polarizing beam splitter, receives the image allocated thereto. For a correct allocation, an upright stereo image is formed. For all arrangements, it is advantageous to mount a variable iris diaphragm BL in or close to the exit pupil AP or to optically

conjugate the iris diaphragm to the exit pupil AP. By varying the diameter of the iris diaphragm BL, the contrast, the resolution, the depth of field and the three-dimensional impression can be varied. This is shown in FIG. 4.

FIGS. 5a and 5b show a transilluminating light arrangement wherein viewing takes place via a monitor M and shutter spectacles SB. This transilluminating light arrangement is shown and explained in detail in United States Patent 5,835,264 and incorporated herein by reference.

FIGS. 5a and 5b show the dynamic method in a one-objective transmitted-light microscope with monitor viewing. The microscope arrangement according to the invention includes a light source (not shown), a collector (not shown), a condenser KO (or similar optic for reflected-light illumination) and an objective OB. The objective OB images an image of the object O via an imaging optic AO onto the video camera VK. A light modulator LM is disposed in the plane of the aperture diaphragm (entry pupil of the objective). The centroid of the illuminating beam is shifted at clock frequency by the light modulator LM so that the beams (a) and (b) occur sequentially and therefore the object is illuminated with an aperture as high as possible at the angle necessary for the stereoscopic viewing without the viewing aperture being limited.

The clock generator A controls the light modulator LM and the video camera VK so that one of the two images of a stereoscopic image is recorded each time. The display of the three-dimensional image takes place via an electronic monitor M which is clocked via the video camera VK for displaying the two images as sectional images. The screen is viewed with shutter spectacles SB. A transducer (for example, an LED) on the display

screen transmits light signals, which are controlled by the clock generator A, and these light signals are received by a sensor at the shutter spectacles SB. The sensor controls the switchover of the openings of the shutter spectacles SB so that each eye sees, at the clock cycle of the light modulator, a corresponding image of the stereoscopic image pair. The repetition rate makes possible a flicker-free image impression.

FIG. 5a shows the beam (a) for illuminating the object O in the first cycle and FIG. 5b shows the beam (b) for the illumination of the object O in the second cycle. If one interchanges the sequence of the beams (a) and (b), then a pseudo stereoscopic image is viewed, that is, the observer sees an image incorrect with respect to depth. Deeper-lying object details appear to lie higher and the higher-lying details appear to lie lower.

In FIG. 6a, an incident light arrangement having illumination via a beam splitter ST1 is shown. In this arrangement, a light modulator LM is mounted in the aperture diaphragm plane of the illuminating beam path and an adjustable diaphragm BL is mounted in the vicinity of the light modulator LM.

The image of the object is imaged via an imaging optic AO into a video camera VK. Imaging of the object via objectives switchable over the entire area likewise makes possible a stereoscopic viewing. The diaphragm BL is preferably of circular shape and is mounted near the entry pupil of the objective.

In FIG. 6a, the beam path for a one-objective reflected-light microscope is shown up to the video camera. In a first cycle, beam (a) illuminates the object O at the stereo angle for the one eye via collector K, condenser KO, a beam

splitter ST1 and an objective OB and, in the second cycle, beam (b) illuminates the object O at the stereo angle for the other eye via the beam splitter ST1. The objective OB takes up the corresponding beam which reaches the video camera VK via the imaging optic AO.

In FIG. 6b, the beam path for a one-objective reflected-light microscope having direct ocular viewing is shown. Here, the imaging optic AO images the entry pupil via the oculars into the eye pupil of the viewer. A 3D-shutter is disposed forward of each ocular and can, controlled by the clock generator A, switch off the transmitted light to the corresponding ocular over the entire area. In FIG. 6b, the shutter is switched on at the left ocular when the beam (a) illuminates the object and the shutter at the right ocular is switched on when the beam (b) illuminates the object. In this way, each eye views only one illuminating beam.

The light modulator LM can be a liquid crystal matrix in accordance with United States Patent 5,835,264.

The depth of field and the resolution of the stereoscopic image can be adapted to the object by varying the inner diameter of the circular diaphragm BL, for example, by means of an iris diaphragm. In this way, an excellent stereoscopic image is viewed. The diaphragm BL is mounted in the region of the entry pupil of the objective in FIGS. 5a and 5b as well as in FIGS. 6a and 6b.

FIG. 7a shows the light relationships in the plane of the aperture diaphragm (entry pupil of the objective) wherein the variable circular diaphragm BL is closed by a small amount. In one clock pulse, the area F1 is illuminated by the illuminating beam and in the next clock pulse, the area F2 of the entry pupil

is illuminated. The centroids of the respective light beams are so adjustable within the illuminating aperture that the object is illuminated at the angle required for stereo viewing.

FIG. 7b shows the light relationships in the plane of the aperture diaphragm (entry pupil of the objective). In addition, a variable central diaphragm ZB is mounted as an opaque circular diaphragm. By varying the outer diameter of the circular diaphragm ZB, the depth of field and the resolution of the stereoscopic image can be adapted to the object so that a stereoscopic image of highest resolution is viewed because the zero diffraction order is partially suppressed and therefore the resolution capacity is increased.

FIG. 7c shows the light relationships in the plane of the aperture diaphragm (entry pupil of the objective). An additional variable central diaphragm is mounted as an opaque rectangular diaphragm. By varying the width (b) of the rectangular diaphragm, the depth of field and the resolution of the stereoscopic image can be adapted to the object so that a stereoscopic image of the highest resolution can be observed. An exchange of different diaphragms can, for example, take place by means of a turret having central diaphragms of different dimensions.

In addition to its modulation function, the light modulator itself can operate advantageously as a diaphragm. This is done by means of the liquid crystal matrix in that a part of the liquid crystal matrix is switched into both switch positions to be partially non-transmissive (dark diaphragm regions) in order to clear the illumination beam path. For example, a rectangularly or circularly-shaped center part can be used as shown in FIGS. 7b and 7c having magnitudes which can be driven so

as to be varied. The realization that the light modulator itself can also be switched as a diaphragm by means of a liquid crystal matrix is shown, for example, in United States Patent 5,835,264 and incorporated herein by reference.

The diaphragm BL utilized in accordance with the invention must not be mounted exactly in the plane of the entry pupil of the objective OB. Deviations are conceivable up to an order of magnitude of approximately 10% of the condenser focal length of the condenser in FIG. 3 from the position of the plane. The diaphragm is advantageously approximately 5% of the condenser focal length away from the position of the light modulator LM.

It is understood that the foregoing description is that of the preferred embodiments of the invention and that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.